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Filter Design in Thirty Seconds

Bruce Carter, Texas Instruments

ABSTRACT

Need a filter – fast? No theory, very little math – just working filter designs, and in a hurry? This is the right article!

1. INTRODUCTION

This document is intended for designers that don't have the time to chase down filter theory in old college textbooks - and try to translate those ugly transfer equations into something that can be put into production. This is like looking at the back of the textbook for the answer. Speaking of the back of the book – Appendix B contains a brief introduction to the filter circuits given here, and the limitations of this "quickie" approach to design.

To design a filter, four things must be known in advance:

- The power supplies available: positive / negative – or only positive (single supply)
- The frequencies that need to be passed, and those that need to be rejected.
- A transition frequency, the point at which the filter starts to work – or – a center frequency around which the filter is symmetrical.
- An initial capacitor value – pick one somewhere from 100 pF for high frequencies to 0.1 mF for low frequencies. If the resulting resistor values are too large or too small, pick another capacitor value.

Ready? Let's design the filter. Pick the frequencies that need to be passed (shaded area) from one of the 6 choices that follow:

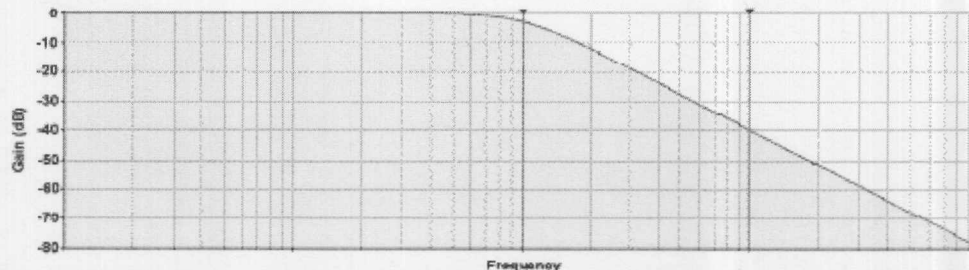


Figure 1. Low Pass Filter – Go to Section 2

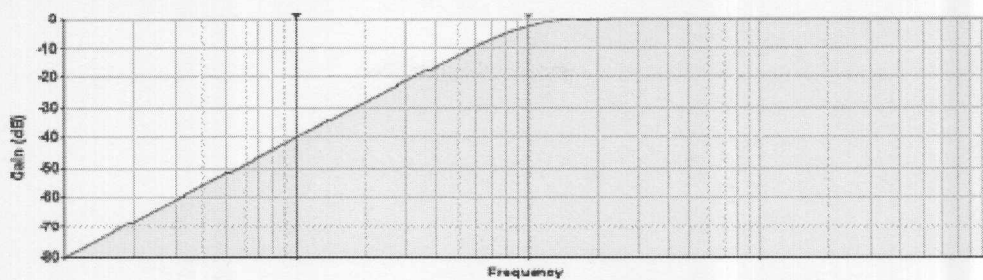


Figure 2. High Pass Filter – Go To Section 3

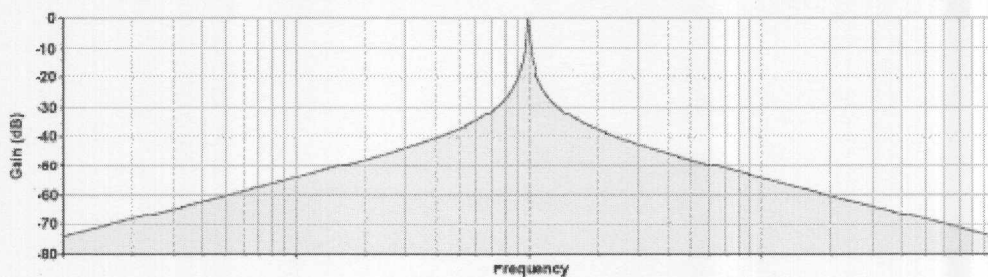


Figure 3. Narrow (Single Frequency) Band Pass – Go To Section 4

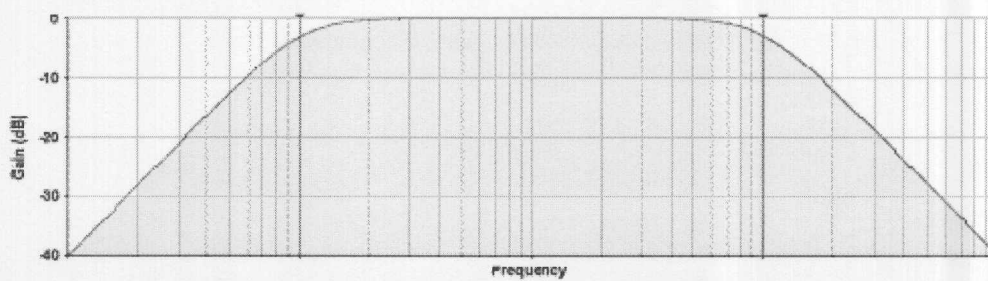


Figure 4. Wide Band Pass – Go To Section 5

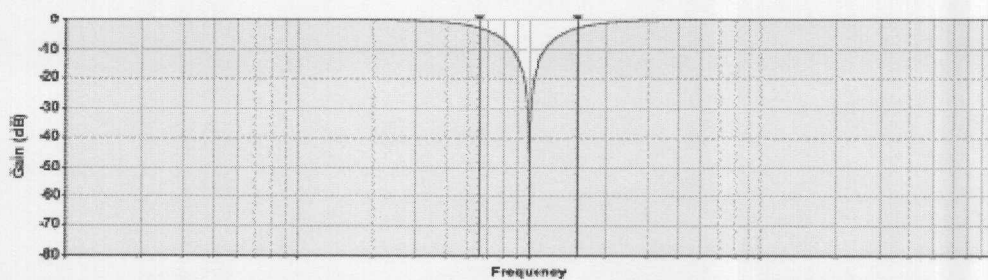


Figure 5. Notch Filter – Single Frequency Rejection

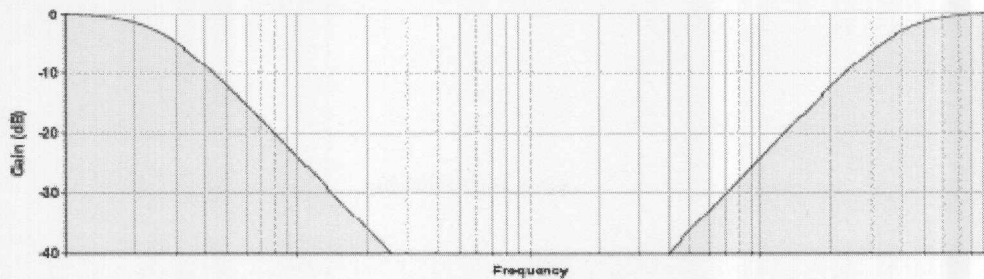


Figure 6. Band Reject Filter

2. Low Pass Filter

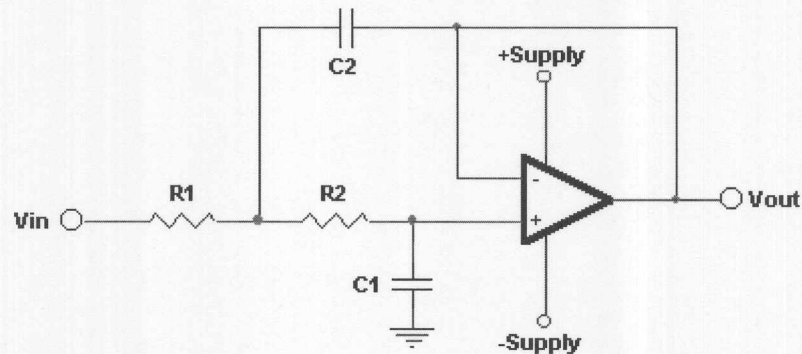
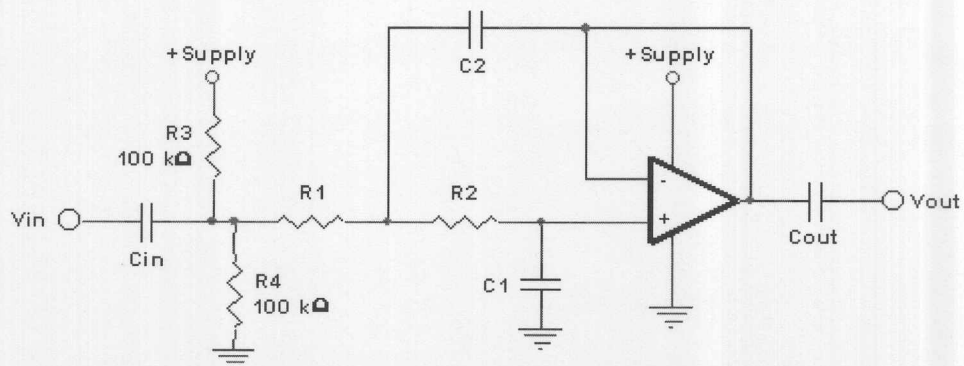
Figure 7. Low Pass Filter for \pm Supplies

Figure 8. Low Pass Filter for a Single Supply

Design Procedure:

- Pick C1 _____
- Calculate $C2 = C1 * 2$: _____
- Calculate $R1$ and $R2 = \frac{1}{2\sqrt{2} * \pi * C1 * \text{Frequency}}$: _____ (pick a standard value from Appendix A).

For Single Supply Case Only:

- o Calculate $C_{in} = C_{out} = 100$ to 1000 times C_1 (not critical): _____

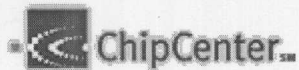
DONE!

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• High Pass Filter

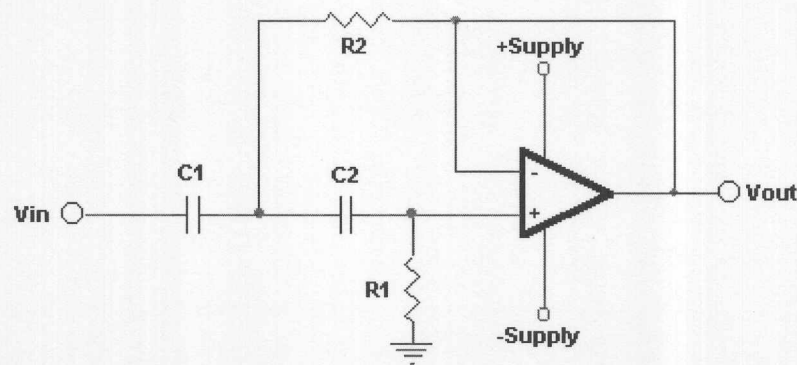


Figure 9. High Pass Filter for \pm Supplies

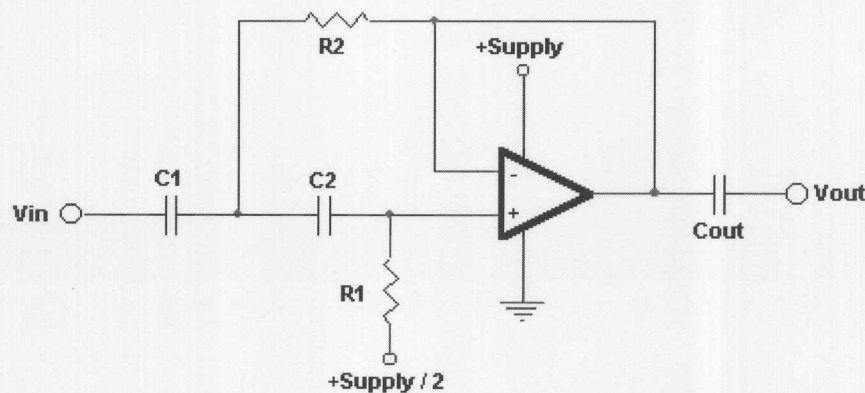


Figure 10. Low Pass Filter for a Single Supply

Design Procedure:

- Pick $C1 = C2$: _____
- Calculate $R1$: $\frac{1}{\sqrt{2} * \pi * C1 * \text{Frequency}}$: _____ (pick a standard value from Appendix A).

- Calculate R2: $\frac{1}{2\sqrt{2} * \pi * C1 * \text{Frequency}}$: _____ (pick a standard value from Appendix A).

For Single Supply Case Only:

- Calculate Cout = 100 to 1000 times C1 (not critical): _____

DONE!

• **Narrow (Single Frequency) Band Pass Filter**

NOTE: These circuits include a gain of 10 (20 dB) at the center frequency.

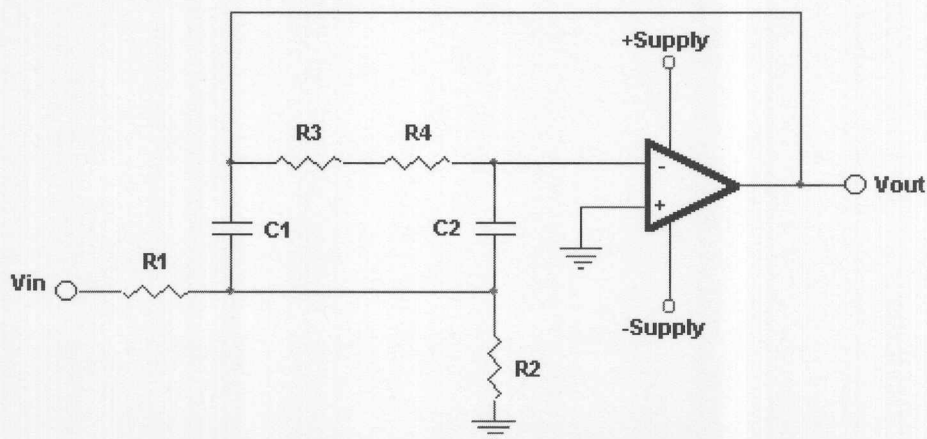


Figure 11. Narrow Band Pass Filter for ±Supplies

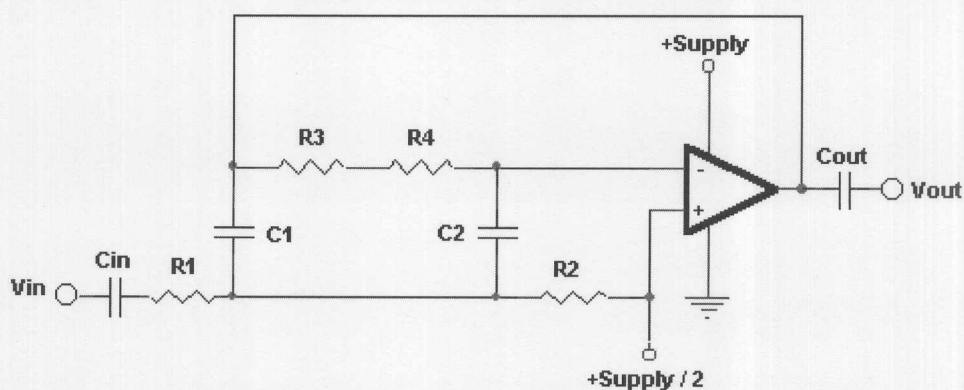


Figure 12. Narrow Band Pass Filter for a Single Supply

Design Procedure:

- Pick C1 = C2: _____

- Calculate $R1 = R4 = \frac{1}{2 * \pi * C1 * \text{Frequency}}$: _____ (pick a standard value from Appendix A).
- Calculate $R3 = 19 * R1$
- Calculate $R2 = \frac{R1}{19}$

For Single Supply Case Only:

- Calculate $Cin = Cout = 100 \text{ to } 1000 \text{ times } C1$ (not critical): _____

DONE!

• Wide Band Pass Filter

NOTE: The start and ending frequencies of the band should be at least five times different.

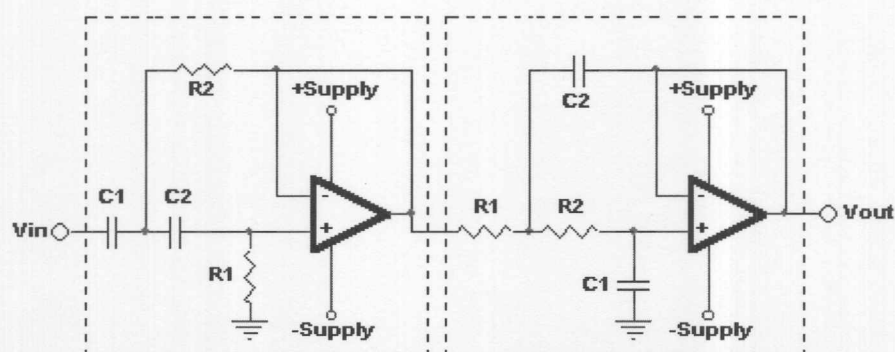


Figure 13. Wide Band Pass Filter for \pm Supplies

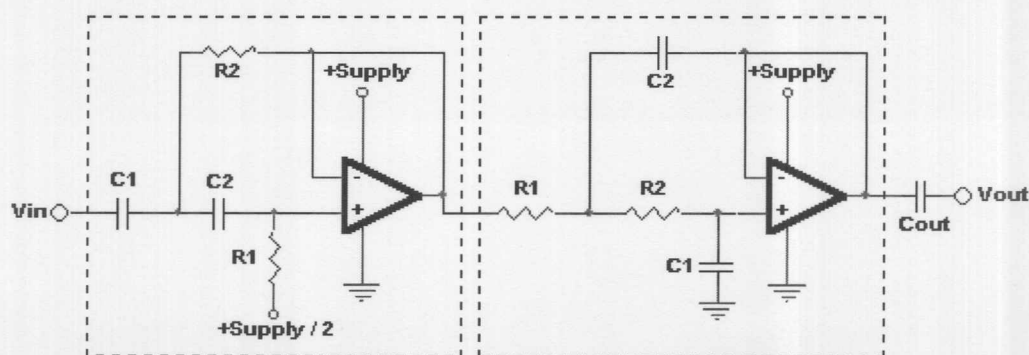


Figure 14. Wide Band Pass Filter for a Single Supply

Design Procedure:

- Go to section 3, and design a high pass filter for the low end of the band.
- Go to section 2, and design a low pass filter for the high end of the band.

For Single Supply Case Only:

- Calculate $C_{in} = C_{out} = 100$ to 1000 times C_1 in the low pass filter section (not critical): _____

DONE!

- **Notch (Single Frequency Rejection) Filter**

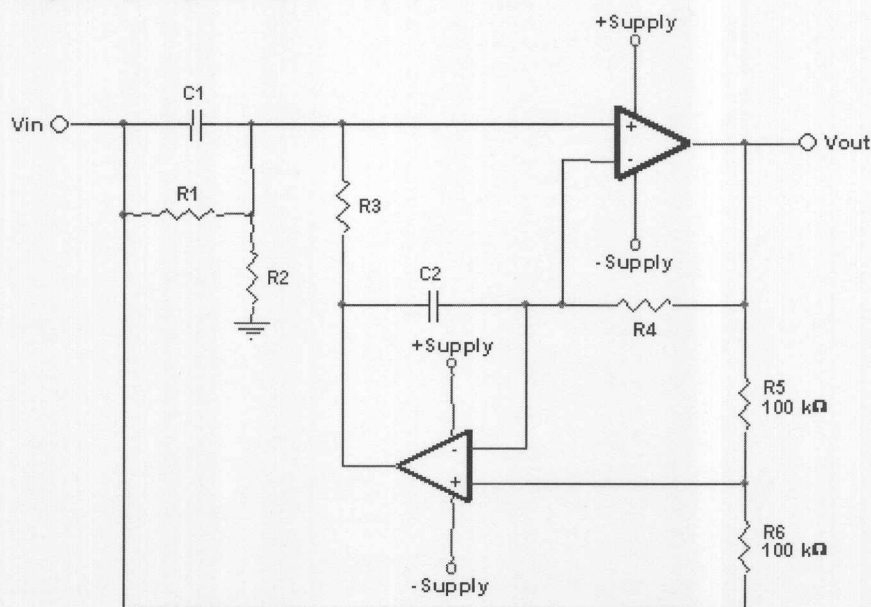


Figure 15. Narrow Band Pass Filter for \pm Supplies

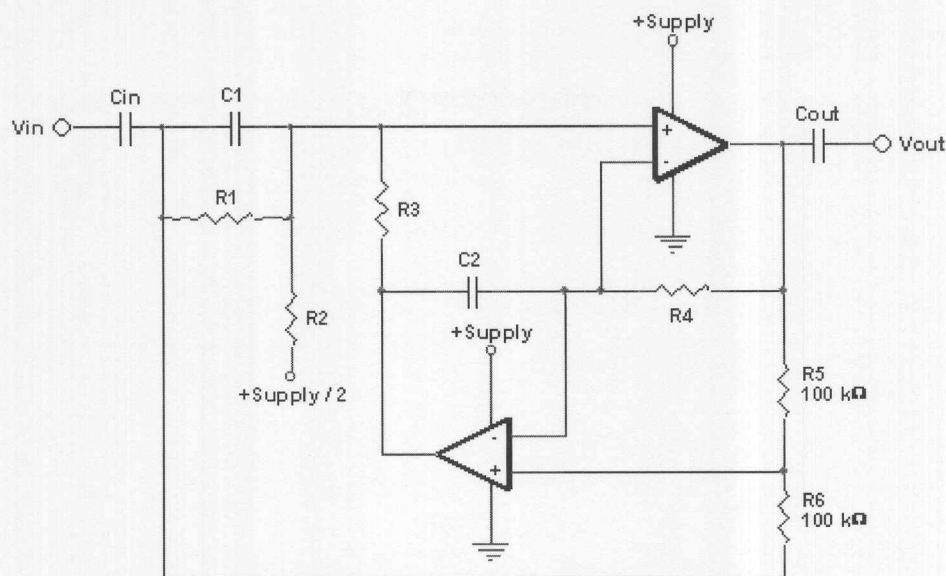


Figure 16. Narrow Band Pass Filter for a Single Supply

Design Procedure:

- Pick $C1 = C2$: _____
- Calculate $R3 = R4$: $\frac{1}{2 * \pi * C1 * \text{Frequency}}$: _____ (pick a standard value from Appendix A).
- Calculate $R1 = R2 = 20 * R3$

For Single Supply Case Only:

- Calculate $Cin = Cout = 100 \text{ to } 1000 \text{ times } C1$ (not critical): _____

DONE!

• Band Reject Filter

NOTE: The start and ending frequencies of the band to be rejected should be at least fifty times different.

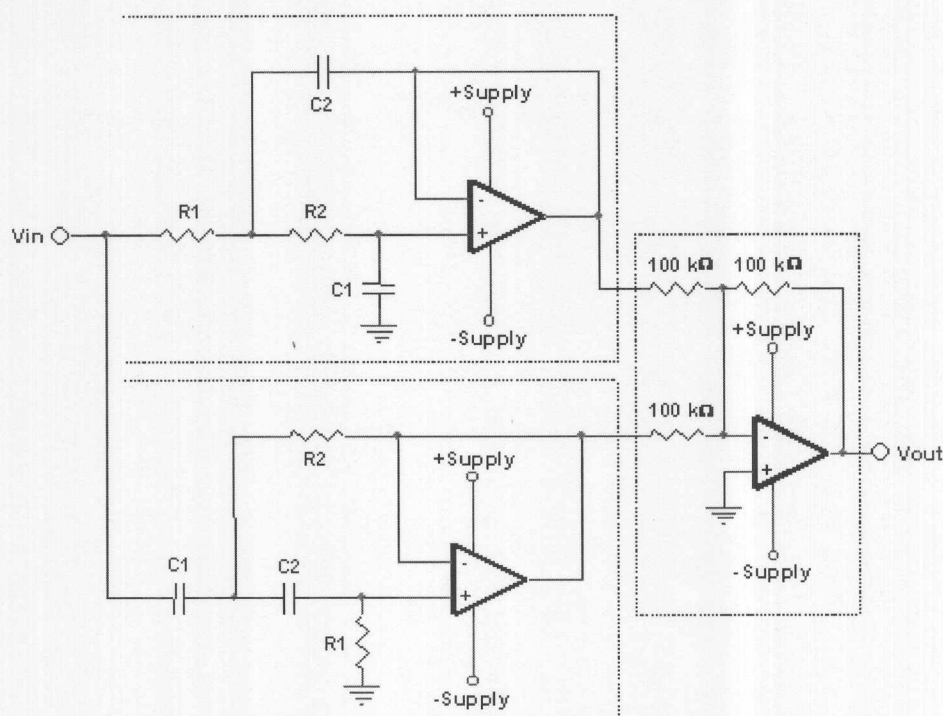


Figure 17. Band Reject Filter for \pm Supplies

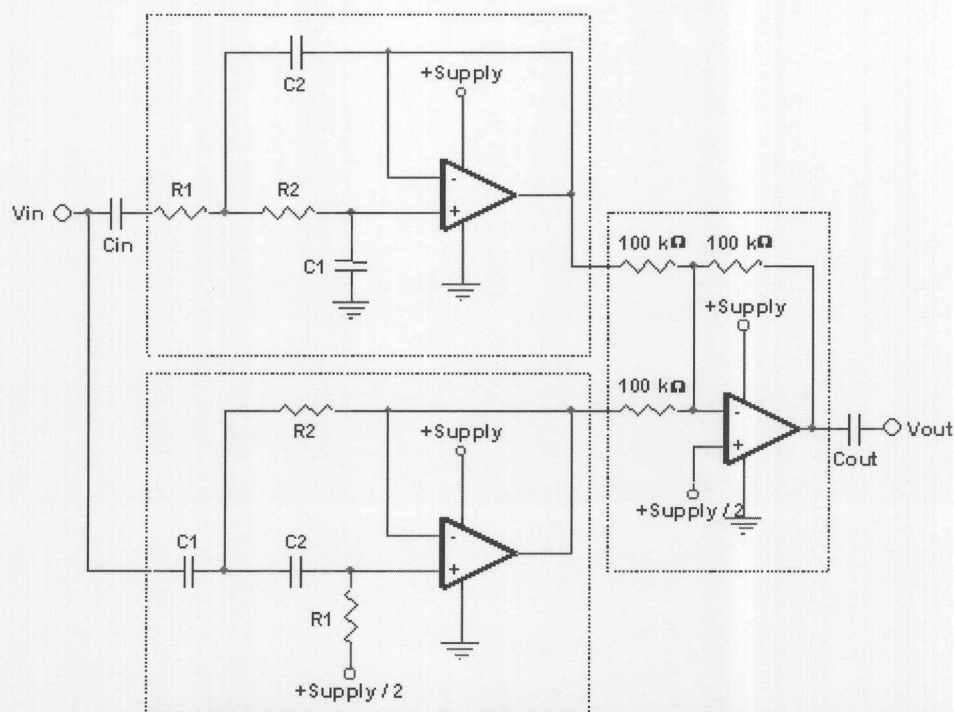


Figure 18. Band Reject Filter for a Single Supply

Design Procedure:

- Go to section 3, and design a high pass filter for the low end of the upper band.
- Go to section 2, and design a low pass filter for the high end of the lower band.

For Single Supply Case Only:

- Calculate $C_{in} = C_{out} = 100$ to 1000 times C_1 in the low pass filter section (not critical): _____

DONE!

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Appendix A – Standard Resistor and Capacitor Values

E-12 Resistor / Capacitor Values

1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, and 8.2; multiplied by the decade value.

E-24 Resistor / Capacitor Values

1.0, 1.1, 1.2, 1.3, 1.5, 1.6, 1.8, 2.0, 2.2, 2.4, 2.7, 3.0, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.5, 8.2, and 9.1; multiplied by the decade value.

E-96 Resistor Values

1.00, 1.02, 1.05, 1.07, 1.10, 1.13, 1.15, 1.18, 1.21, 1.24, 1.27, 1.30, 1.33, 1.37, 1.40, 1.43, 1.47, 1.50, 1.54, 1.58, 1.62, 1.65, 1.69, 1.74, 1.78, 1.82, 1.87, 1.91, 1.96, 2.00, 2.05, 2.10, 2.15, 2.21, 2.26, 2.32, 2.37, 2.43, 2.49, 2.55, 2.61, 2.67, 2.74, 2.80, 2.87, 2.94, 3.01, 3.09, 3.16, 3.24, 3.32, 3.40, 3.48, 3.57, 3.65, 3.74, 3.83, 3.92, 4.02, 4.12, 4.22, 4.32, 4.42, 4.53, 4.64, 4.75, 4.87, 4.99, 5.11, 5.23, 5.36, 5.49, 5.62, 5.76, 5.90, 6.04, 6.19, 6.34, 6.49, 6.65, 6.81, 6.98, 7.15, 7.32, 7.50, 7.68, 7.87, 8.06, 8.25, 8.45, 8.66, 8.87, 9.09, 9.31, 9.53, 9.76; multiplied by the decade value.

Appendix B – Filter Notes (for the More Technically Minded)

Low Pass Filter

The filter selected is a unity gain Sallen Key Filter, with a Butterworth response characteristic. Numerous articles and books have been written describing this topology.

High Pass Filter

The filter selected is a unity gain Sallen Key Filter, with a Butterworth response characteristic. Numerous articles and books have been written describing this topology.

Narrow Band Pass Filter

The filter selected is a modified Deliyannis Filter. The Q is set at 10, which also locks the gain at 10, as the two are related by the expression:

$$\frac{R3 + R4}{2 \cdot R1} = Q = \text{Gain}$$

A higher Q was not selected, because the op amp gain bandwidth product can be easily reached, even with a gain of 20 dB. At least 40 dB of headroom should be allowed above the center frequency peak. The op amp slew rate should also be sufficient to allow the waveform at the center frequency to swing to the amplitude required.

Wide Band Pass Filter

This is nothing more than cascaded Sallen Key high pass and low pass filters. The high pass comes first, so energy from it that stretches to infinite frequency will be low passed.

Notch Filter

This is the Fliege Filter topology, set to a Q of 10. The Q can be adjusted independently from the center frequency by changing R1 and R2. Q is related to the center frequency set resistor by the following:

$$R1 = R2 = 2 * Q * R3$$

The Fliege Filter topology has a fixed gain of 1.

The only real possibility of a problem is the common mode range of the bottom amplifier in the single supply case.

Band Reject Filter

This is nothing more than summed Sallen Key high pass and low pass filters. They cannot be cascaded, because their responses do not overlap as in the wide band pass filter case.

Author bio:

Bruce Carter is a Senior Applications Engineer at Texas Instruments. He authors books, magazine articles and applications notes, and gives seminars across the country on analog design using high speed op amps. He also assists customers who have difficult application problems. Mr. Carter is a 1978 graduate of Texas Tech University in Engineering Physics, and a 1979 graduate of the University of Texas in Electrical Engineering.

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